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Refraction corrected transmissions imaging based on Bézier curves: first results with KIT 3D USCT

The computational complexity of wave-based image reconstructions is very high. For this reason, approximations for 3D are required. Here, ray-based approaches are commonly used. The straight ray approximation neglects physical effects like refraction. Bent ray approaches like the widely used fast marching method may include this effect yet are still computationally demanding, especially in 3D. The Bézier curve technique, introduced by Perez-Liva et al., could be a compromise between computational effort and image quality. In this work, the method was extended to 3D. Additionally, it was evaluated with respect to third order Bézier curves and an optimization of parameters was carried out.

The Bézier curve technique uses a brute-force search to determine the path from the emitter to the receiver with minimum time-of-flight (TOF) given an estimated sound speed map. The path is chosen out of a set of Bézier curves with different curvature and the emitter and receiver as start- and endpoint. The Bézier curve with the minimal TOF is selected. The reconstruction is formulated as a linear equation system (Mx = b) which is solved for the image x with the TVAL algorithm, given the refracted path matrix M and the TOF difference to an empty measurement b.

The evaluation was carried out on two datasets. One bent ray iteration was performed based on the straight ray reconstruction. First, simulation data was created with the k-wave toolbox, with a speed of sound inhomogeneity and senders and receivers arranged in a hemisphere. The Bézier curve method produces similar results to the fast marching method. The mean squared error of the Bézier curve technique is 9.98 m/s in comparison to fast marching (11.85 m/s) and straight ray (15.09 m/s). Both bent ray techniques were able to represent the object size better, however differ in the speed of sound values in the border regions, see Fig. 1. Applied to a real data of the KIT 3D USCT both methods performed similarly: the object size was better preserved using bent ray methods (Fig. 2).

The method shows first promising results on 3D simulation data as well as real data. For simple objects, the Bézier method leads to similar result like the fast marching method. The representation of the object size has improved, i.e. the Bézier curve method well approximates the main refraction on the object-water interface. A 3D GPU implementation is currently developed to compare the computation time for 3D USCT.

Author: ZUCH, Franziska

Co-authors: Dr HOPP, Torsten; Mr ZAPF, Michael; Dr RUITER, Nicole

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